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Slow axis collimation lens with variable curvature radius for semiconductor laser bars

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ABSTRACT

Based on Snell's law and the constant phase in the front of optical field, a design method of the slow axis collimation lens with variable curvature radius is proposed for semiconductor laser bars. Variable radius of the collimator is designed by the transmission angle, and it is demonstrated that the collimator has good beam collimation ability by material with low refractive index. Resorting to the design thought of finite element method, the surface of the collimator has been divided, and it is feasible to be fabricated. This method is applied as an example in collimation of a 976 nm semiconductor laser bar. 6 mrad divergence angle of collimated beam at slow axis is realized by the designed collimation lens with refraction index of 1.51.

Contents

1. Introduction

Due to the properties of high power, high electrical–optical conversion efficiency, small volume and low cost, semiconductor lasers have been widely used in many fields [1,2]. However, direct applications of high brightness and high power semiconductor lasers have been confined by the unsatisfied beam quality, especially poor beam quality in slow axis. In slow axis, the typical full divergence angle of half maximum intensity (FWHM) is 8°, and the numerical aperture (NA) is 0.07 [1–5]. The full divergence angle of 90% energy (90% E) is 10–14°, and it is significantly larger than that of FWHM [1].

Many beam collimation methods have been proposed in recent years. However, the typical divergence angle (FWHM) of the collimated beam at slow axis for semiconductor laser bars (full bar) is 2–5° [1–8]. The beam collimation of slow axis is one of the

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bottleneck in achieving high brightness and high power of semiconductor laser bars. Generally, the slow axis collimation lens (SAC) for semiconductor laser bar is micro-cylinder lens, and it has been designed based on the paraxial approximation. Due to large spherical aberration, after beam collimation the divergence angle is 40 mrad with 0.06 NA [3,4]. Another collimator is aspheric lens, and spherical aberration can be decreased efficiently by it. However, the beam at slow axis should be considered as a point light source during design, and hence, aspheric lens is better as collimator for fast axis [1,5]. Gradient-index lens [6,7] and diffractive elements [8] have been used as collimation lens for semiconductor laser. Both of them are difficult to fabricate elements with the necessary high numerical aperture [6–8]. In addition, the good beam collimation ability of collimation lenses much depend high refraction index of lens material [3–5].

However, the beam at slow axis has large size (100–200 μm) [1–5] and large divergence, and it is non-paraxial beam [9–15]. The beam of semiconductor laser at slow axis cannot be collimated well based on paraxial approximate, and new collimator should be proposed. In this work, the collimation lens with variable curvature radius is proposed and designed based on the non-paraxial Gauss model of semiconductor laser beam at slow axis. And the designed collimator has good beam collimation ability with low refraction index. Based on the finite element method, the surface of the designed lens is discretized, and the lens can be feasibly fabricated by micro-manufacturing. The beam collimation of a 976 nm laser bar is taken as an example, and three different lenses with refractive index of 1.51 are designed and illustrated. In slow axis, 6 mrad divergence angle of collimated beam of laser bar is realized by the lens with 10 division parts of each emitter. The design method of SAC for semiconductor lasers can be prospective in high power and high brightness applications.

2. Design principle

2.1. Analysis of transmission angle

Fig. 1 shows the transmission angle of a beam, where Y and Z are slow and transmission axes, respectively. O is the original of the axis, and it is in the light source. $E(y, z)$ is the electrical field intensity of the beam; l is the tangent of $E(y, z)$; θ and s are the oblique angle and normal of l, respectively. The transmission angle denoted by φ is an included angle between the transmission direction of the beam and transmission axis of Z, and it can be calculated based on constant phase in the front of the field.

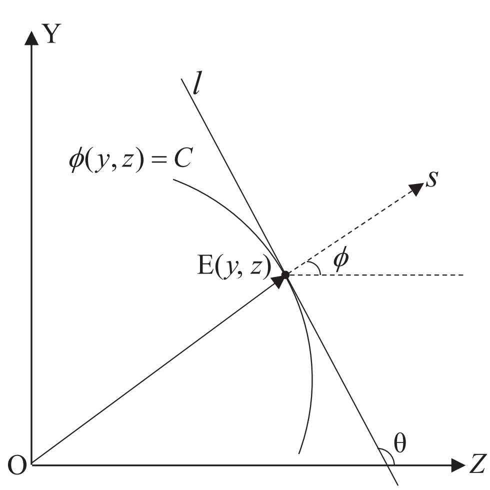

Fig. 1. The transmission angle of a beam field $E(y, z)$.

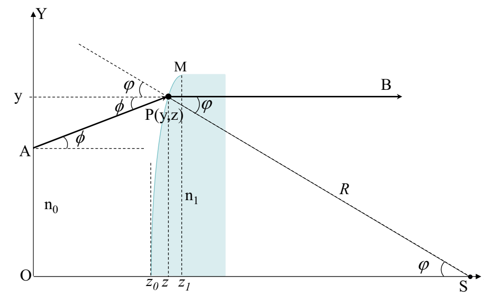

Fig. 2. The principle of beam collimation.

In free space, the transmission field of the beam can be expressed as

$$E(y, z) = A(y, z)\exp[-i\phi(y, z)], \tag{1}$$

where $A(y, z)$ and $\phi(y, z)$ are amplitude and phase distribution of the field, respectively. The constant phase is calculated by $\phi(y, z) = C$. As shown in Fig.1, the transmission angle of ϕ is calculated and written as

$$\phi = \arctan\left[-\frac{\frac{d\phi(y,z)}{dz}}{\frac{d\phi(y,z)}{dy}}\right] - \frac{\pi}{2} \tag{2}$$

2.2. Collimation lens design

Fig. 2 shows the principle of beam collimation. M is the curvature surface of the collimation lens, and AP and PB are incident and collimated beam, respectively. n_0 and n_1 denote the refractive index of free space and collimation lens, respectively. R is the curvature radius of M, and φ is the included angle between radius of Rand transmission axis of Z, and the transmission angle of φ is also marked in the figure.

According to Snell's law, it can be expressed as

$$\frac{\sin(\phi + \varphi)}{\sin\varphi} = \frac{n_1}{n_0} \tag{3}$$

As shown in Fig. 2, the relationship between R and φ can be expressed assin $\varphi = \frac{y}{R}$. Combined with Eq. (3), the curvature radius of R can be solved and written as

$$R = y\sqrt{\left(\frac{n_1}{n_0\sin\phi} - \mathrm{ctg}\phi\right)^2 + 1} \tag{4}$$

As shown in Eq. (4), the curvature radius of R is determined by position of y and transmission angle of ϕ which is calculated by Eq. (2).

2.3. Finite element design and fabrication approach

The curvature surface of the collimation lens designed by Eq. (4) is a complex continuous surface, and it is difficult to process directly. Hence, the curvature surface of the lens should be divided and redesigned. The surface of the lens is divided into N parts, and the larger the value of N is, the better the beam collimation result will be achieved. The division thought is analogy to the design though of finite element method (FEM), of which the accuracy of the simulation result depends on the number of subdivisions of the analytic object, and the more the number of subdivisions is, the more accurate result will be obtained [1,16].

The designed lens is symmetrical along z axes, and the analyses shown in the following figures are done in the space of $y > 0$. Fig. 3 is a schematic diagram shows the radius distribution along the y